Gas Scintillation Profile Monitors

11th ICFA International Mini-Workshop on Diagnostics for High-Intensity Hadron Machines

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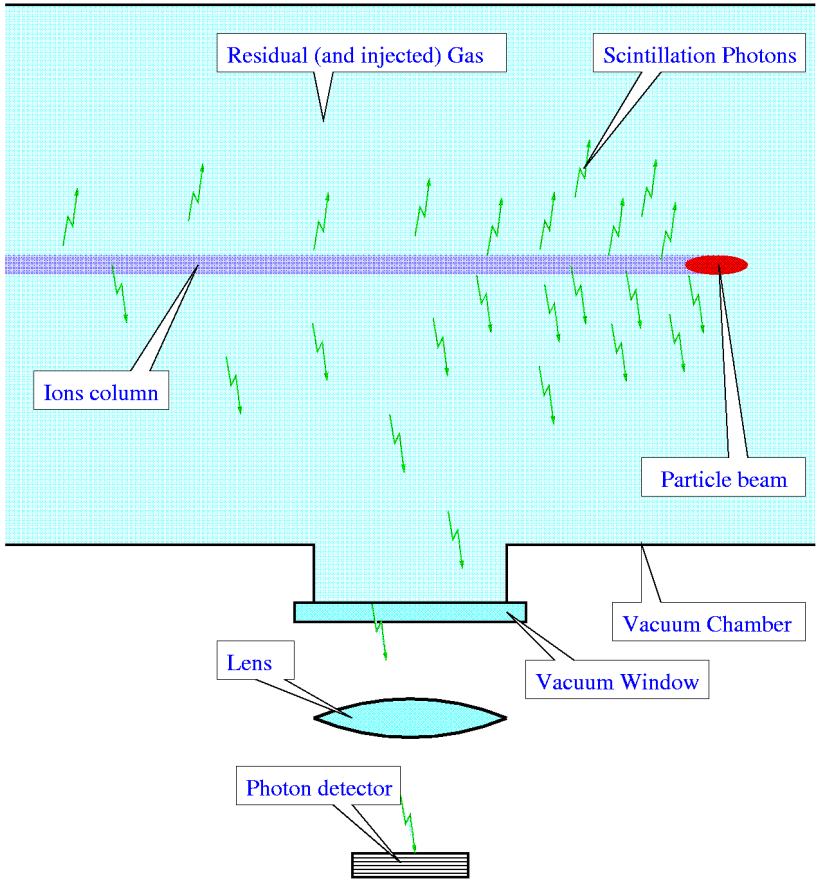
by Mike Plum

Introduction

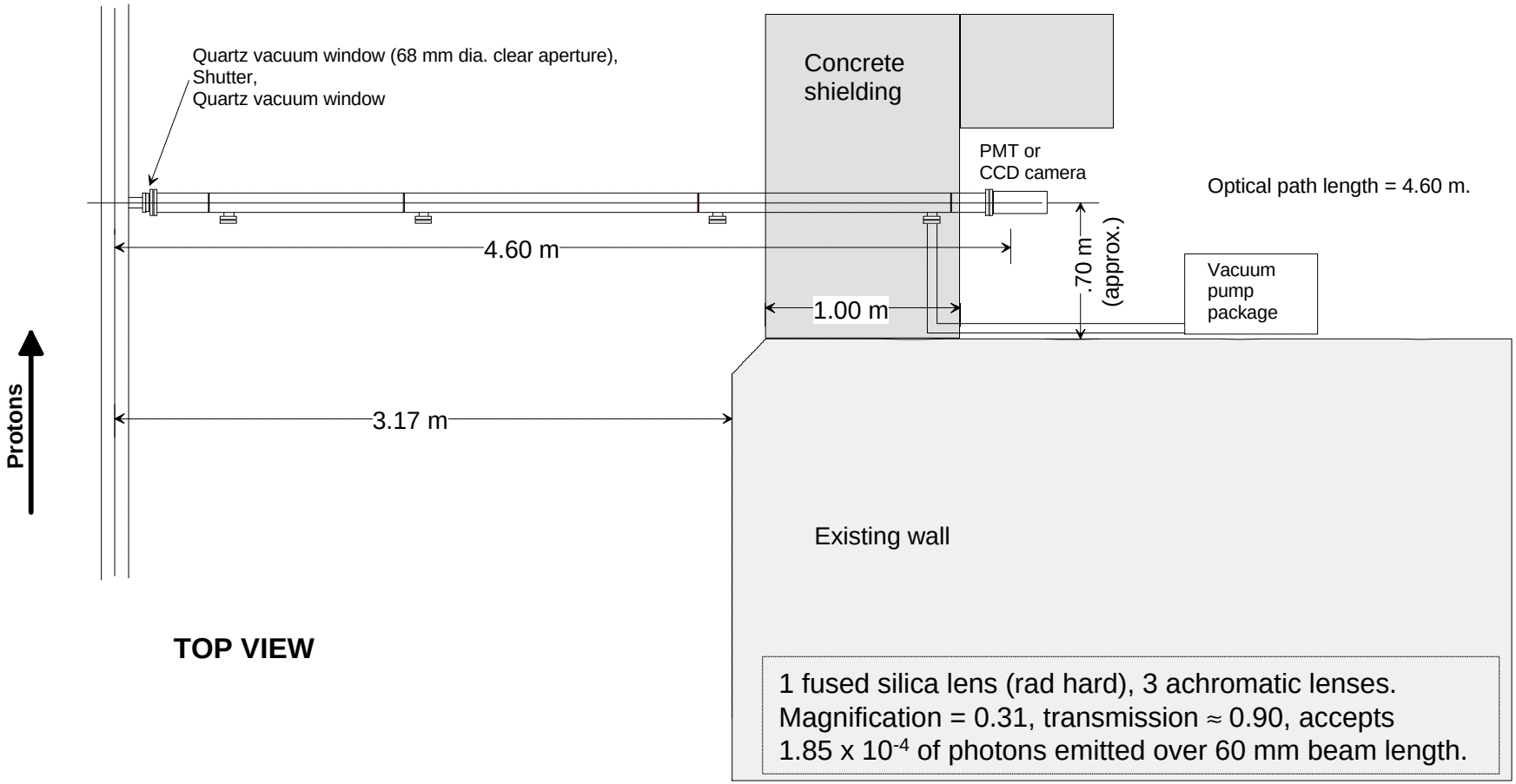
- Residual gas ionization profile monitor is impractical for the CERN PS due to space limitations. Would like to build gas scintillation profile monitor.
- Accurate gas scintillation cross section measurements have been made for N_2 gas at 200 keV incident proton energy, and accurate lifetime measurements have been made at 400 keV.
- However, the proton energy range for the CERN PS is 1.4 to 25 GeV – far above the 200 keV measurements. Can we trust that the cross sections will simply scale with dE/dx, and that the lifetimes will be unchanged? dE/dx scaling predicts cross sections 250 times smaller!
- Rough measurements at high energies around our range of interest have been made, but the various measurements do not seem to be consistent, in terms of either the cross sections or the lifetimes. **Jung and SL/BI Group, Kakimoto, Jones, Actis.**
- Our measurements will also be useful to the world-wide beam diagnostics community, to help other labs with gas scintillation detector development.

Gas Scintillation

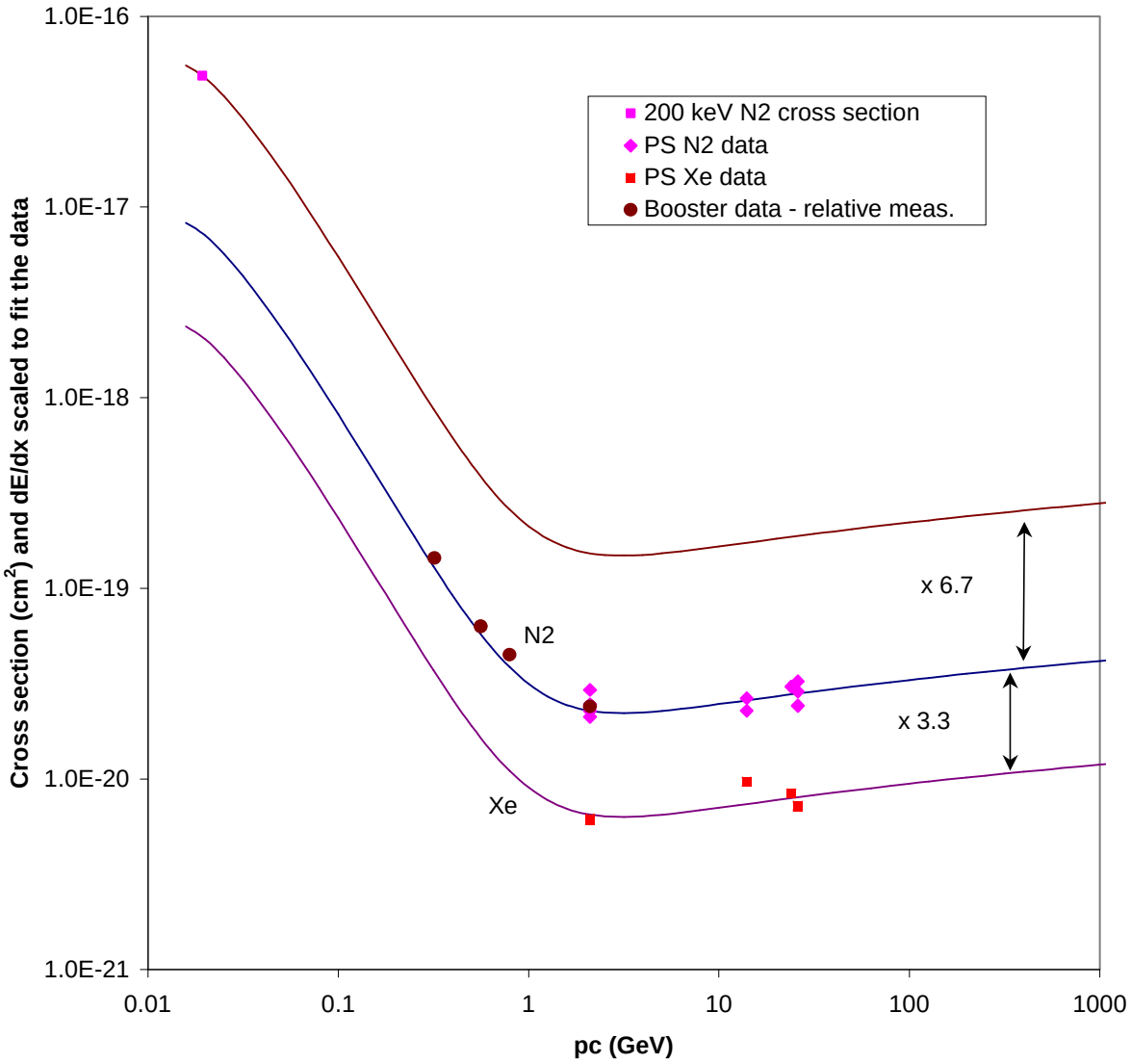


- **Gas molecules in the beam pipe, from either residual or injected gas, interact with the passing particle beam.**
- **Electrons are promoted to excited states.**
- **When the electrons fall to lower energy orbitals, photons are emitted.**
- **Photons are collected to measure the profile.**

PS Optical System



Cross section vs. momentum



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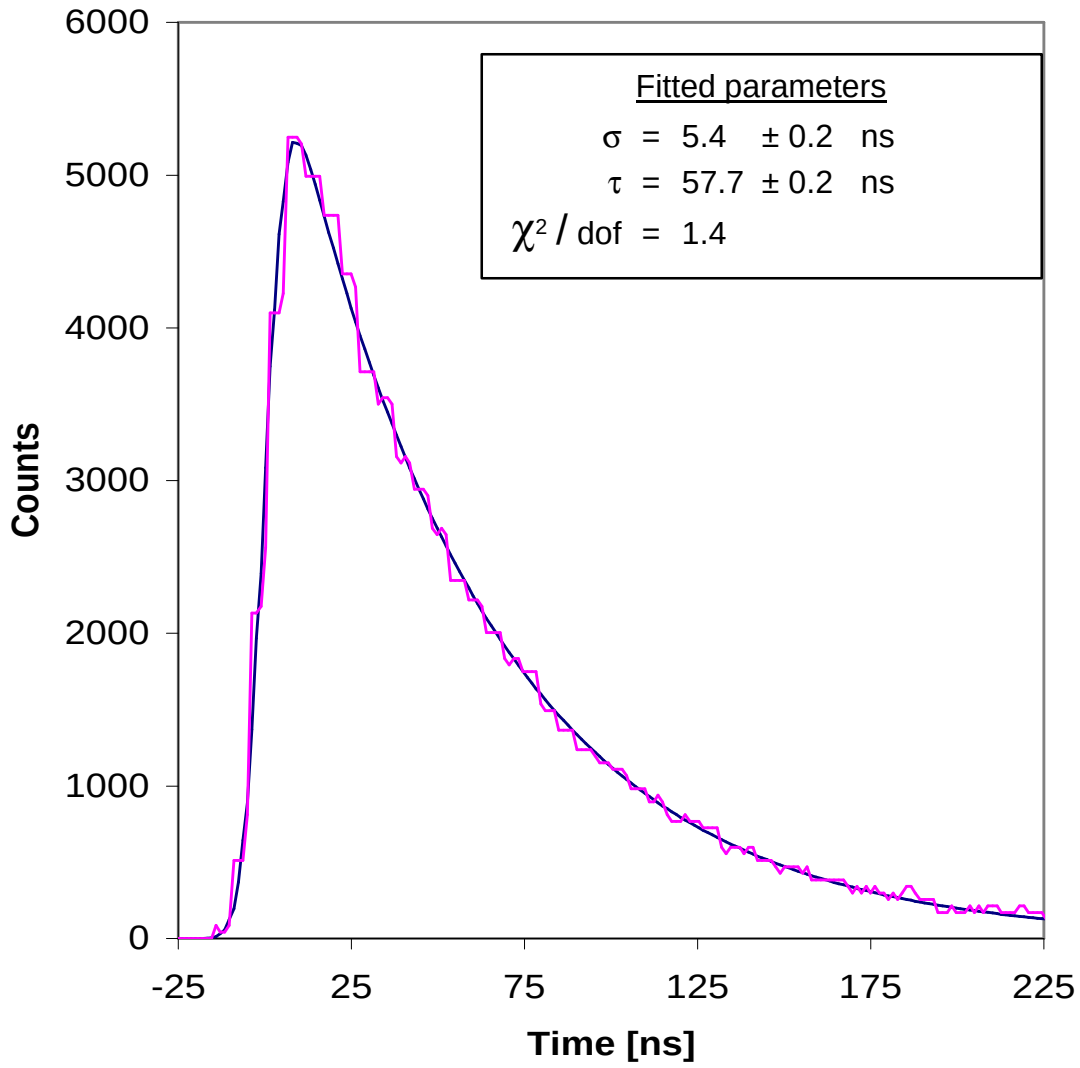
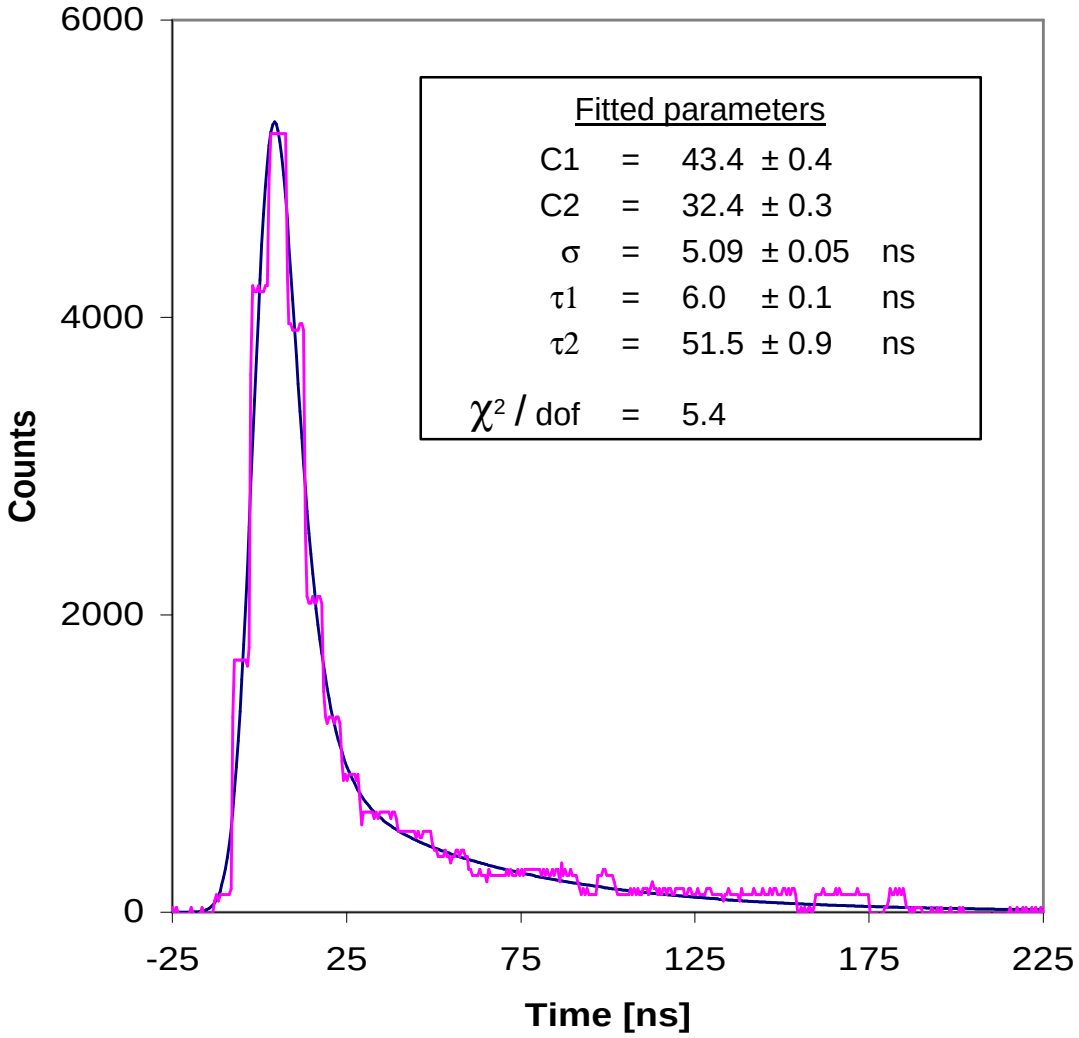
N_2 lifetime, no filter



Gas pressure:
1.03×10^{-6} Torr

Beam momentum:
26 GeV/c

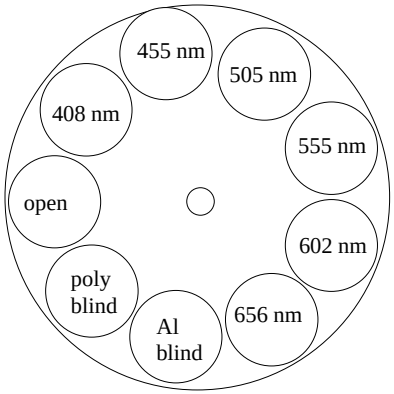
Xe lifetime, no filter



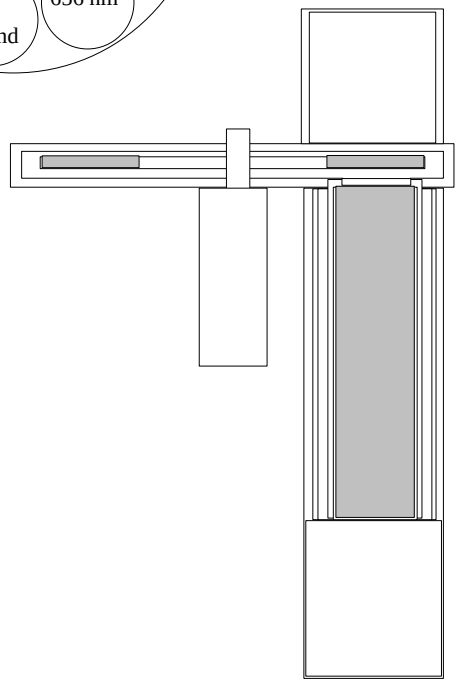
Gas pressure:
1.25×10^{-6} Torr

Beam momentum:
26 GeV/c

Interference Filter Setup

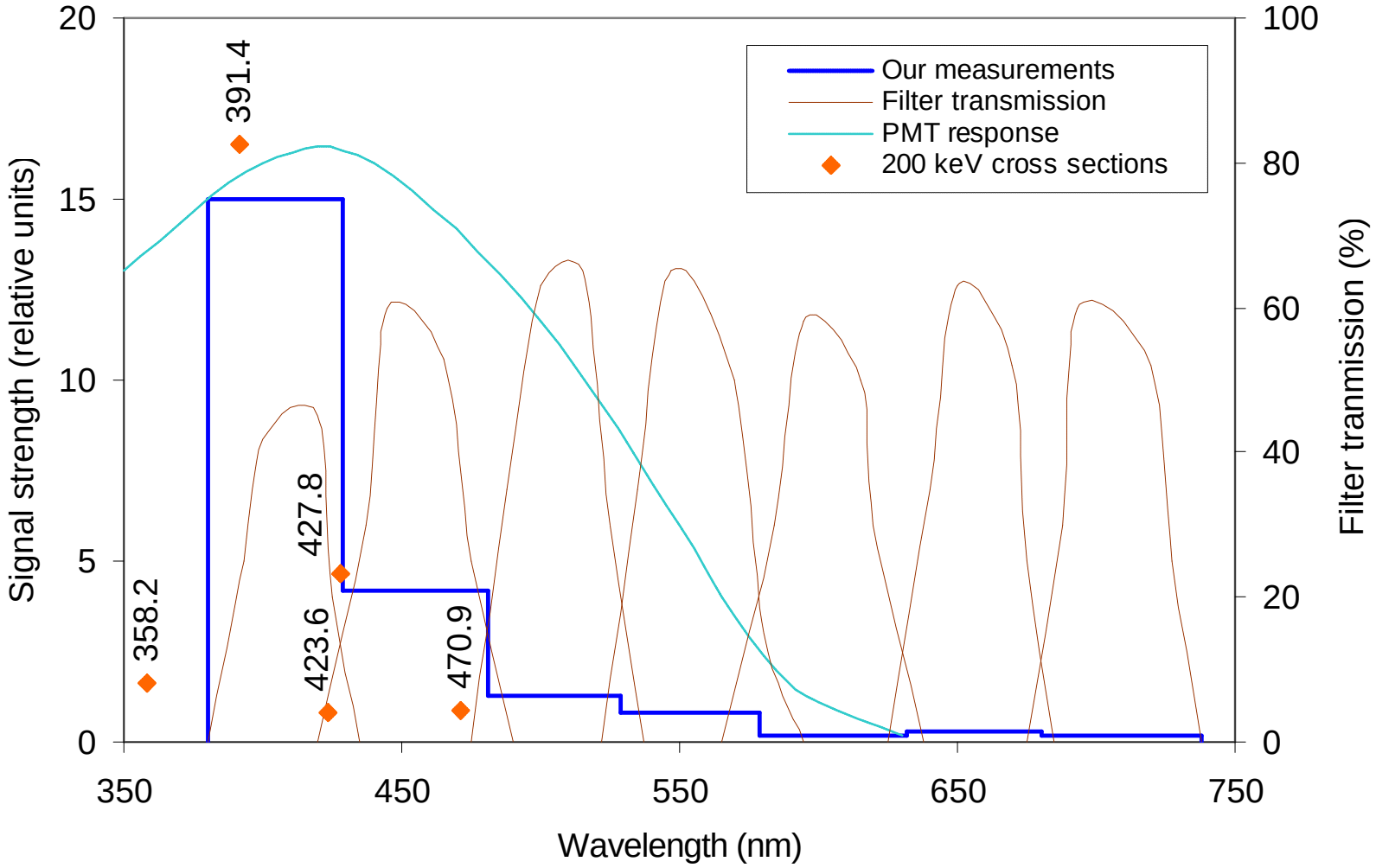


Filter wheel



XP2020 PMT

N_2 spectral measurements



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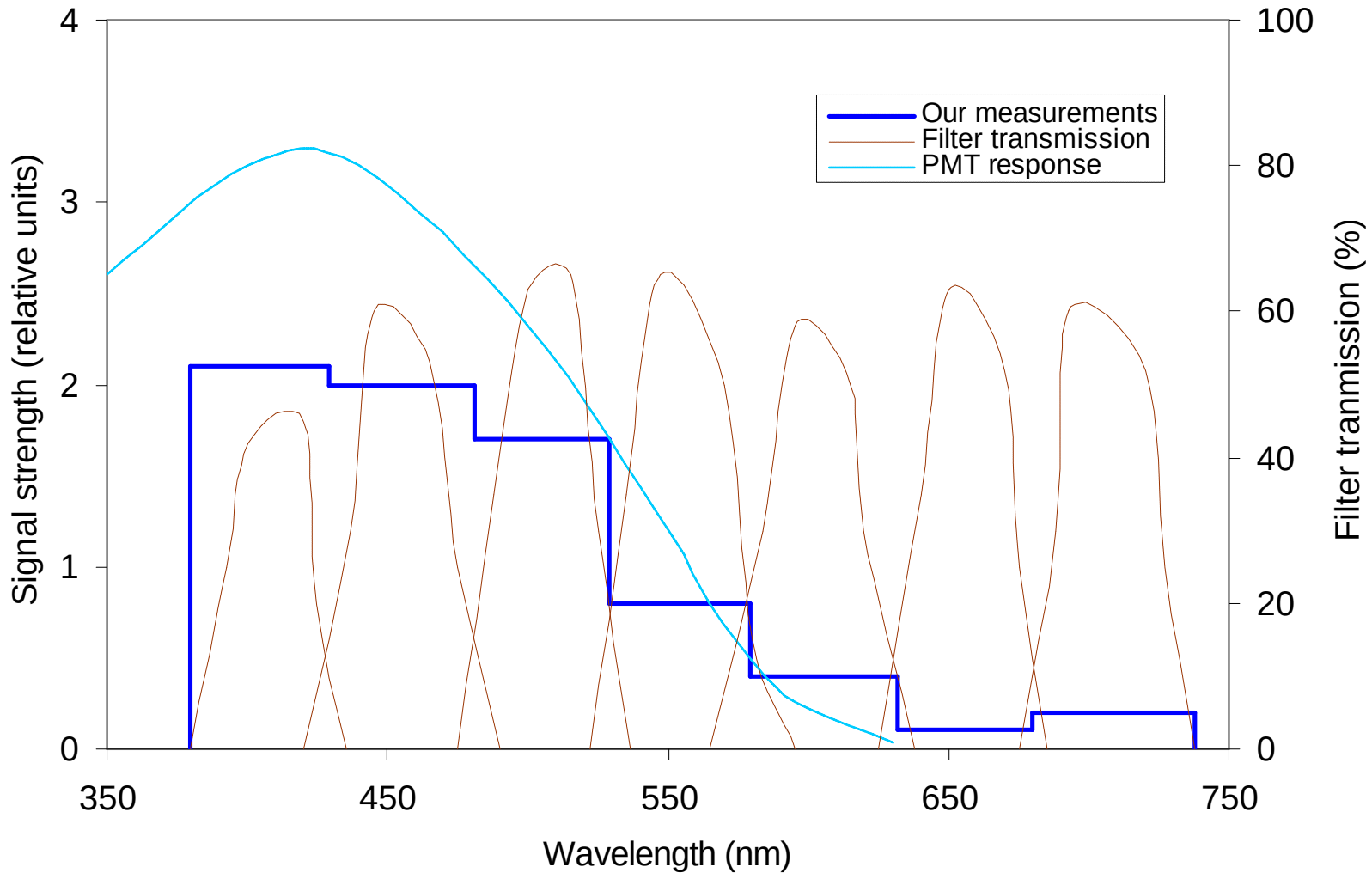
Xe spectral measurements



Results summary

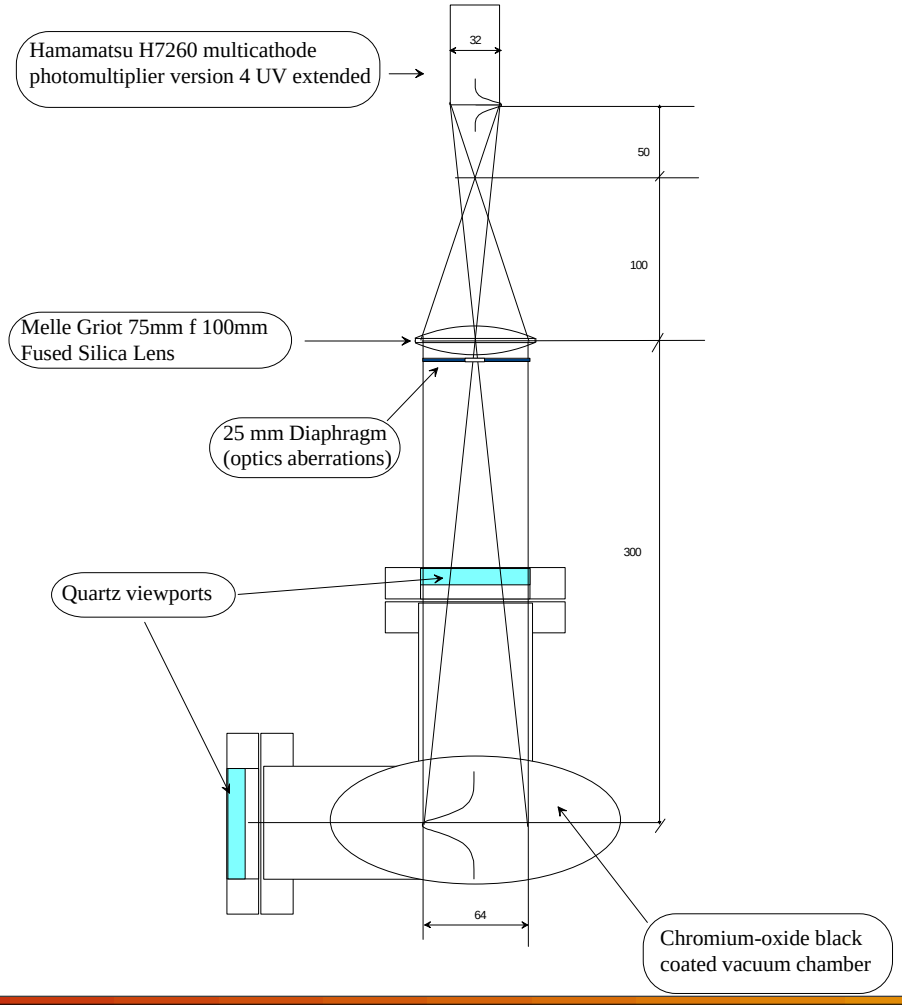
- Cross sections:
  - N_2 cross sections are 6.7 times less than expected from dE/dx scaling of previous measurements made at 200 keV.
  - Xe cross sections are 3.3 times lower than the N_2.
- Spectrum:
  - The N_2 spectrum is concentrated around 391 nm.
  - The Xe spectrum is broad-band.
- Lifetimes:
  - N_2 lifetimes are consistent with previous measurements of 60 ns.
  - One single time constant. Lifetime is not shorter if use filter.
  - Xe has at least two components to the lifetime - one quite short (6 ns), and one long (52 ns), with roughly equal areas. Lifetimes are a bit shorter if use filter (4 and 49 ns).

"N2 and Xe Gas Scintillation Cross-Section, Spectrum, and Lifetime Measurements from 50 MeV to 25 GeV at the CERN PS and Booster, M.A. Plum, J. Bosser, E. Bravin, and R. Maccaferri, Nucl. Instr. & Meth. A492 (2002) 74-90.

32 channel PMT tests

- We built a rad-hard prototype profile monitor based on a 32 channel (1 mm pitch) position sensitive photomultiplier tube.
- Also used rad-hard vacuum window (quartz), and rad-hard lens (fused silica).
- Installed in Section 1 of the PS.
- Horizontal profile measurement system is located on specially-built, blackened vacuum tank.
- Vertical profile system is temporarily located on an old flange inside the downstream end of magnet 100.
- Front-end electronics is located in tunnel below the PS.

32 ch. PMT profile measurement



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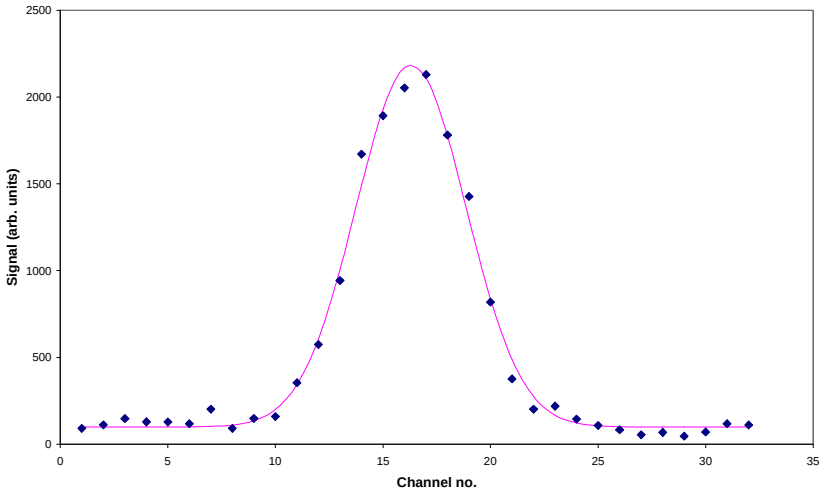
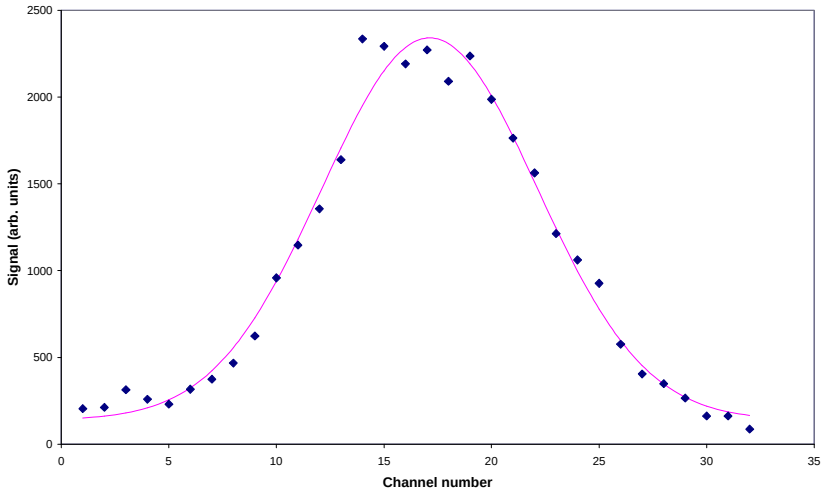
32 Ch. PMT profiles

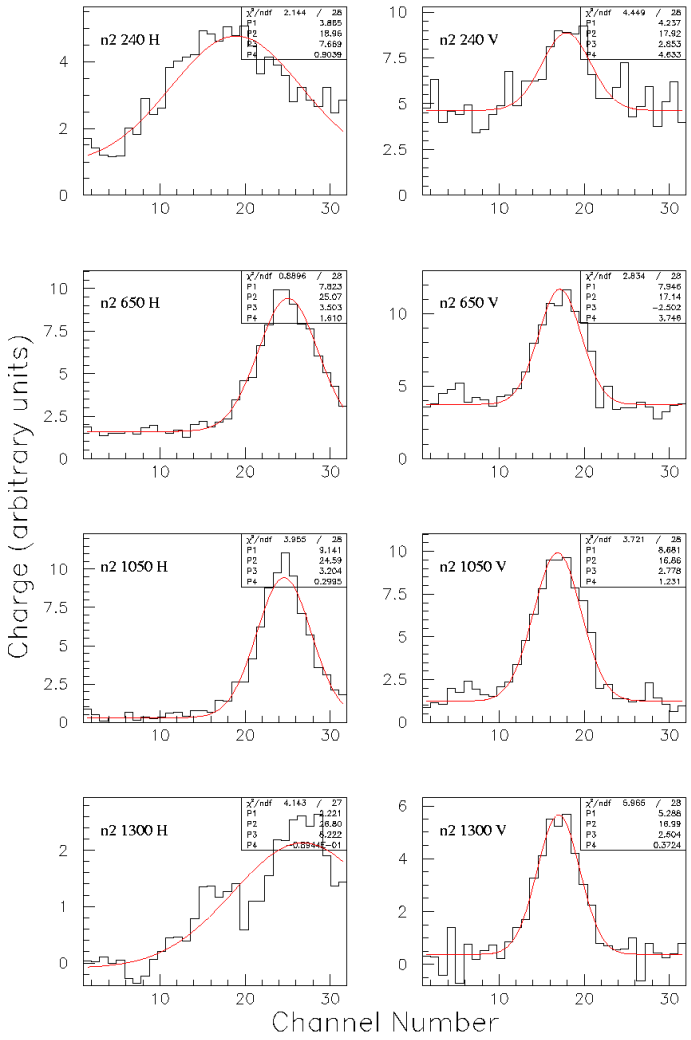




TSTLHC beam cycle
26 GeV/c
5 x 10^{12} protons
20 ms
1.5 x 10^{-6} Torr N_2 gas

AD beam cycle
26.4 GeV/c
1.6 x 10^{13} protons
20 ms
0.8 x 10^{-6} Torr N_2 gas

32 ch. PMT, N2

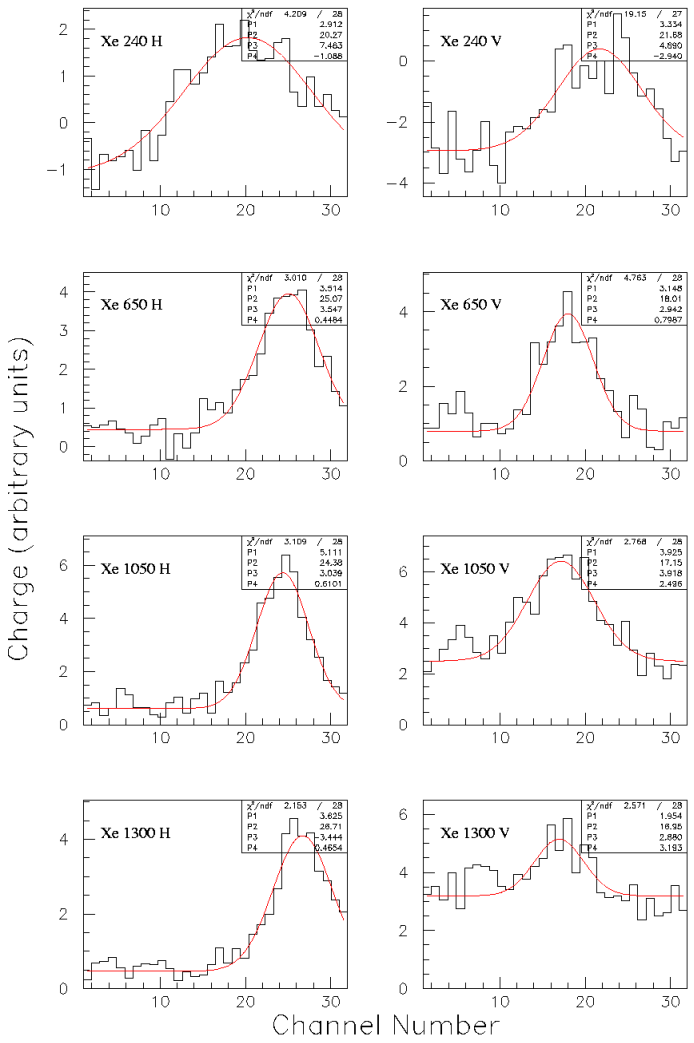


Beam cycle:
MD1

Gas pressure:
1.43 x 10^{-6} Torr

Beam momenta:
2.1 GeV/c
14 GeV/c
24 GeV/c
26 GeV/c

32 ch. PMT, Xe



Beam cycle:
MD1

Gas pressure:
1.83×10^{-6} Torr

Beam momenta:
2.1 GeV/c
14 GeV/c
24 GeV/c
26 GeV/c

32 Channel PMT Results

- Check for self consistency:
  - Horizontal profiles – 32 ch. PMT data agrees with wire scanner measurements.
  - Vertical profiles – 32 ch. PMT data shows profile about 30% larger than wire scanner.
  - Horizontal positions – good agreement with beam position monitor.
  - Vertical positions – poor agreement with beam position monitor, at least for the case of the MD1 cycle. Note - beam may have been unstable.
- When beam loss is high, or beam intensity is low, signal to noise ratio is too poor to make a good measurement.
- 32 channels are not enough to get sufficient resolution *and* account for a wide range of beam positions.

Gas scintillation vs. residual gas ionization

- Both gas scintillation and residual gas ionization profile monitors are being considered for the SNS ring.
- Both processes rely on beam particle energy loss to create the photons and ions.
- A useful photon from N_2 gas requires about 3.6 keV energy loss, and a ionization event requires about 35 eV.
- In a gas scintillation profile monitor only a small fraction of the photons reach the detector – in the CERN PS case it was 0.015. In a gas ionization profile monitor, every ion can be collected.
- Gas ionization monitors are therefore times more efficient!

$$\frac{3.6\,\text{keV}}{35\,\text{eV}} \cdot \frac{1}{0.015} = 6{,}900$$

Gas scintillation vs. residual gas ionization

	Gas scintillation	Gas ionization
Signal level	1	6,900
Sensitive to background electrons	No	Yes
Sensitive to beam loss	Yes	Less than gas scintillation
Real estate requirement	Low	Medium
Beam perturbation	None	Need EM fields plus corrector magnets
Excited state lifetime important?	Yes	No
Technology well developed?	No	Yes

Summary

- Gas scintillation cross sections, lifetimes, and spectra have been measured for N_2 and Xe at the PS.
- The N_2 cross sections are about 6.7 times lower than expected from dE/dx scaling (which is not too bad!).
- N_2 lifetimes and spectra are consistent with low energy measurements.
- Xe cross sections are about 3 times less than for N_2.
- Xe lifetimes have at least two components - one quite short, and one about as long as the N_2.
- Xe spectra is broad band, at least over our range of measurement.
- Preliminary tests of a prototype rad-hard profile measurement system for the PS show profiles that are sometimes noisy due to beam loss.
- In many cases profile monitors based on residual gas scintillation may be better due to the higher signal levels and sensitivity to beam loss.